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The Relationships between Setting Time and Early Age Strength of Concrete containing Silica fume, Fly ash and Slag

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ABSTRACT

Setting times are considered as identification boundary of fresh and hardened states of concrete. Initial setting time governs the transportation, casting, compacting and finishing processes and, on the other hand the final setting time governs the strength development of the concrete. In the present work, the effects of silica fume, fly ash and slag, as partial replacement for cement, in presence of superplasticiser on the setting times and strength development of different concrete mixtures were examined. The results showed that utilization of pozzolanic materials retarded the setting times of the mixtures. The more replacement contents led to increase of setting times. The results also indicated that silica fume enhanced both the early and later age strength. Fly ash increased the later stage strength but had a negative impact on the early age strength. Subsequently, the early age strength and final setting time relationships were expressed by the experimental equations.

Keywords: Setting time; Compressive Strength; Silica Fume; Fly Ash; Slag

INTRODUCTION

Knowledge of the setting characteristics of concretes govern the concreting schedule such as transporting, placing, compacting and finishing of concrete. They also highly affect the hardened properties of concrete. Despite the important role of setting times on the performance of concrete they are not so distinguished within hydration process. This is due to the fact that the fresh and hardened processes have overlap duration (Neville, 1997; Mehta and Monteiro, 1993; Brooks et al. 2000). By increasing utilization of different pozzolanic materials, due to the environmental aspect and the superior effect on the fresh and hardened concrete properties, in high performance concrete establishment of setting times characteristics became more important (Mazloom et al. 2004). Since the cementing materials possess different chemical and mineralogical compositions as well as different particle characteristics, they could have different effects on the properties of concrete inclusive setting characteristics of concrete (Brooks et al. 2000). It is also well known that the setting times are affected, by water cement ratios, casting temperature, air temperature, type and dosage of admixtures and also compositions of cement (Kruml, 1990; Eren et al. 1995; Sivasundaram et al. 1989). The objective of the present work was to examine the effects of different pozzolans and water-cement ratio on the setting times and strength development of concrete.

MATERIALS

The composition of cement and the cementitues materials is given in Table 1. Coarse aggregate with a maximum particle size of 19 mm and fine aggregate with a 3.4 fineness modulus were used in this experiment. The specific gravity and water absorption of the coarse and fine aggregates were 2.61 and 2.04%, and 2.56 and 2.3%, respectively. A high range water reducer agent with the commercial name of Carboxylic 110 M (BASF) was used to adjust the workability of the concrete mixtures. Eleven concrete mixtures with water-binder ratios of 0.35, 0.45 and 0.55 were prepared. In selected specimens with 0.45 water-cement ratio, silica fume, fly ash and slag were used as partial replacement for cement. The replacement content (by weight) was 7% for silica fume, 15% or 25% for fly ash and 25% or 35% for slag. The mixing procedure was as follows: the binder and fine aggregate were mixed initially for 1 min, and half of the mixing water and superplasticiser were mixed for 2 minutes. The coarse aggregate and the rest of the water were added and mixed for 5 min.

Table 1. The compositions of cement, silica fume, fly ash and slag

Chemical Components	Cement Type 1-425	Silica Fume	Fly Ash	Slag
SiO_2	21.41	92.9	47.8	25
Al_2O_3	4.88	1.2	24.9	6.85
Fe_2O_3	3.82	0.74	8.7	3
CaO	63.69	0.02	4-10	57.5
SO_3	2.36	0.1	0.9	1.25
MgO	1.56	1.0	1-2.5	4.51
Na_2o	0.47	0.42	1.2	0.45
K_2o	0.65	1.32	3.6	0.9
Mn_2O_3	-	0.04	0.1-0.2	-
Compounds				
C_3S	51.59	-	-	-
C_2S	22.48	-	-	-
C_3A	6.47	-	-	-
C_4AF	11.62	-	-	-

MIX PROPORTIONS AND TEST PROCEDURE

Table 2 prepares the mix proportions. The initial and final setting times of the concrete mixtures were determined in accordance to ASTM C403 (1995). The test was performed on mortar, which obtained by sieving freshly mixed concrete through a No.4 sieve, and measuring the force required for a needle to penetrate 25 mm into the mortar. Initial and final setting times are defined as the times at which the penetration resistance reached values of 3.5 and 27.6 MPa, respectively. The compressive strength tests (BS 1983) were also performed after 1, 2, 3, 7, 28, 56 and 91 days on 100×100×100 mm cubic specimens.

Table 2. Mix proportions of the concrete mixtures

Concrete Mixes	Sand (ssd)	Gravel (ssd)	Water	Silica Fume	Fly Ash	Slag	Cement	S.P	Slump
	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	gr/m^3	cm
W0.55C375	784.0	958.2	206.3	-	-	-	375.0	-	11.0
W0.55C325	818.8	1000.8	178.8	-	-	-	325.0	-	8.0
W0.45C375	812.0	992.4	168.8	-	-	-	375.0	750	12.5
W0.45S.F7	807.8	987.4	168.8	26.3	-	-	348.8	1125	7.0
W0.45C425	767.3	937.8	191.3	-	-	-	425.0	850	10.5
W0.45F.A15	805.8	984.9	168.8	-	56.3	-	318.8	750	12.0
W0.45F.A25	801.7	979.8	168.8	-	93.8	-	281.3	750	10.5
W0.45S25	808.4	988.1	168.8	-	-	93.8	281.3	750	6.5
W0.45S35	807.0	986.4	168.8	-	-	131.3	243.8	750	10.0
W0.35C425	816.8	998.3	148.8	-	-	-	425.0	2337	8.0
W0.35S.F7F.A15	805.1	984.0	148.8	29.8	63.8	-	331.5	2337	10.5

RESULTS AND DISCUSSIONS

Compressive Strength. The strength development of 0.45 water-cement ratio mixtures made by different cementing materials are shown in Figure 1. It is clear that the strength of all concrete mixtures increased as the age of the mixtures increased. However, the ratio of the strength development is dependent on the type and content of the pozzolanic materials. Adding silica fume, at 7% replacement for cement, remarkably increased compressive strength from early to later ages. Typically, the later age strength of the silica fume specimens increased 16% more than that for the reference one. On the contrary, a reduction of compressive strength was attained at both early and later ages of 35% slag specimens. The results also show that when slag was used at low replacement for cement (25%), a tendency for increasing of later age strength is observed. The fly ash specimens attained lower compressive strength at early age but higher strength at later age, compared to the reference specimens. This may be due to the fact that pozzolan specimens contain lower C_3A and C_3S which diminish the rate of hydration and led to the low early strength. However, due to the pozzolanic reaction of fly ash and slag the later age strength increased more rapidly than those reference specimens.

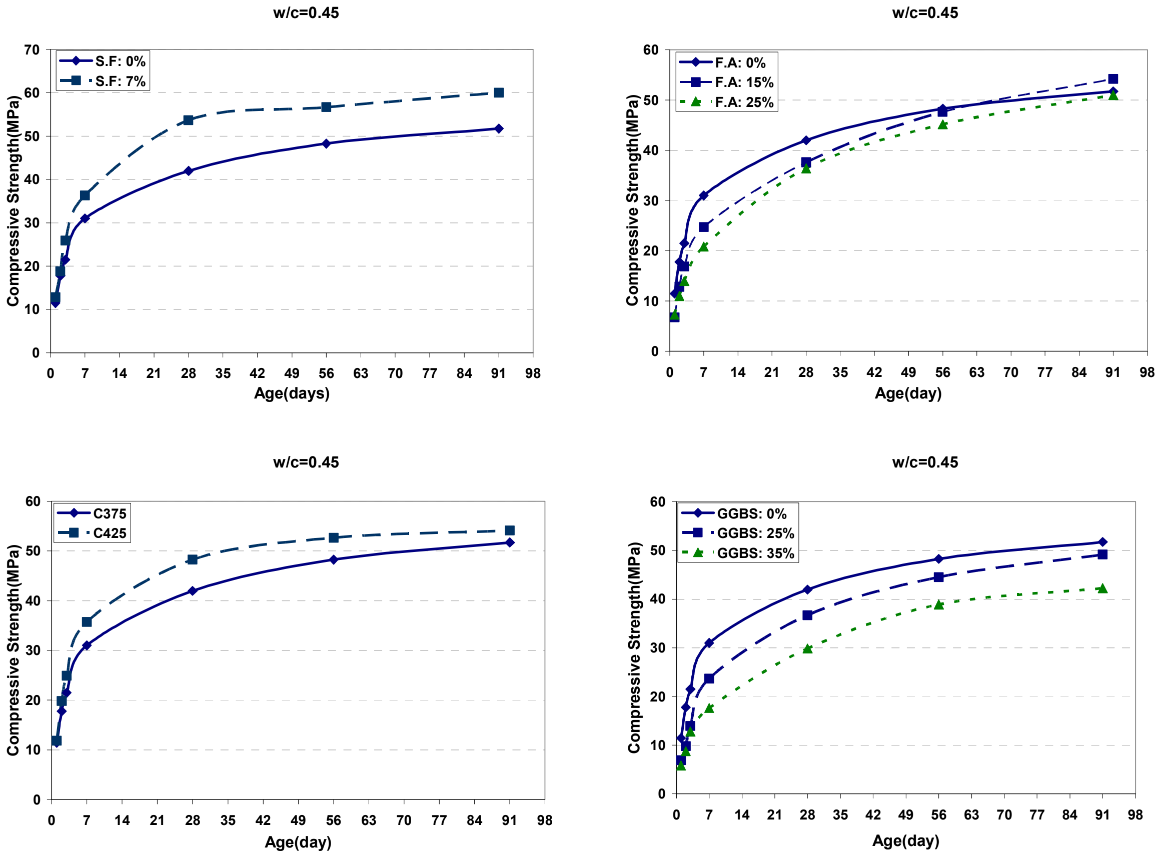

Figure 1. Strength development of concrete mixtures (w/c:0.45)

Figure 2 depicts the strength developmet of the specimens (w/c=0.35) containig both fly ash and silica fume. As shown, a significant increase in the compressive strength at the age of 28 days was obtained. The maximum later age strength of 75 MPa corresponded to the fly ash silica fume specimens. Figure 3 shows the effect of cement content on strength development of 0.55 water cement ratio specimens.

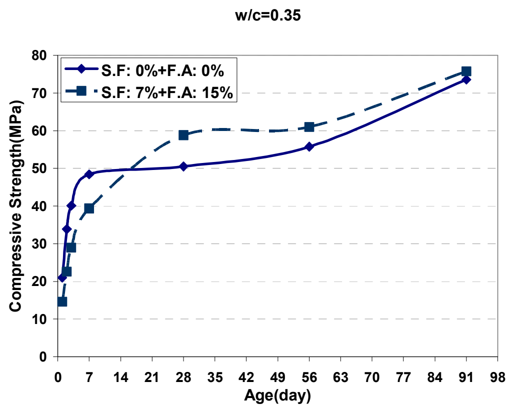

Figure 2. Strength development of concrete mixtures (w/c:0.35)

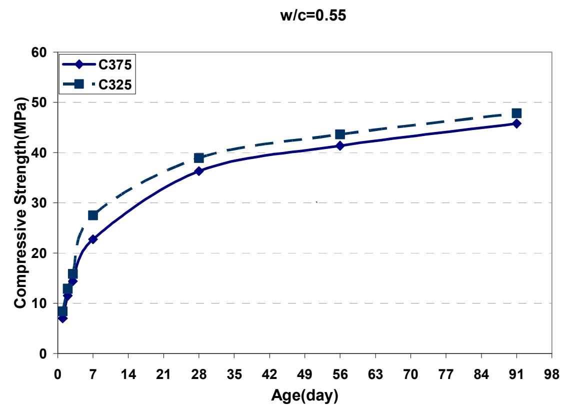

Figure 3. Strength development of concrete mixtures (w/c:0.55)

Figure 4 illustrates the rate of strength development relative to the 7 days strength of 0.45 water cement ratio specimens. As shown the maximum ratios are belonging to the fly ash and slag specimens. This attributed to the fact that hydration of pozzolanic materials (except for silica fume) is low at early age and it becomes high at later ages. The minimum and maximum strength ratios are belonging to the Portland cement and 25% fly ash specimens, respectively.

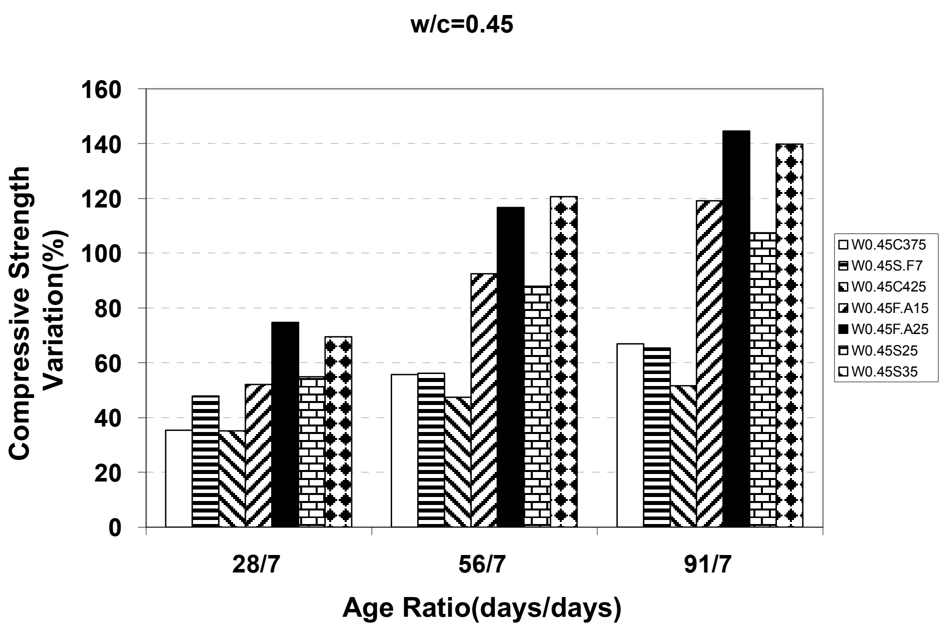

Figure 4. Variation of compressive strength ratios (w/c:0.45)

The strength ratio for 0.35 water-cement ratio specimens is also depicted in Fig. 5. As shown a considerable increase of strength ratios was attained in fly ash-silica fume specimens compared to the reference specimens which declared the effectiveness of hybrid pozzolanic materials on the later hydration. As shown the adding of pozzolan materials to the specimens affect the hydration process in early and later ages. Figure 6 also shows the rate of strength development for 0.55 water cement ratio specimens produced by 325 or 375 Kg/m^3. It shown, that the rate of strength development was increased as the cement content increased from 325 kg/m^3 to 375 kg/m^3.

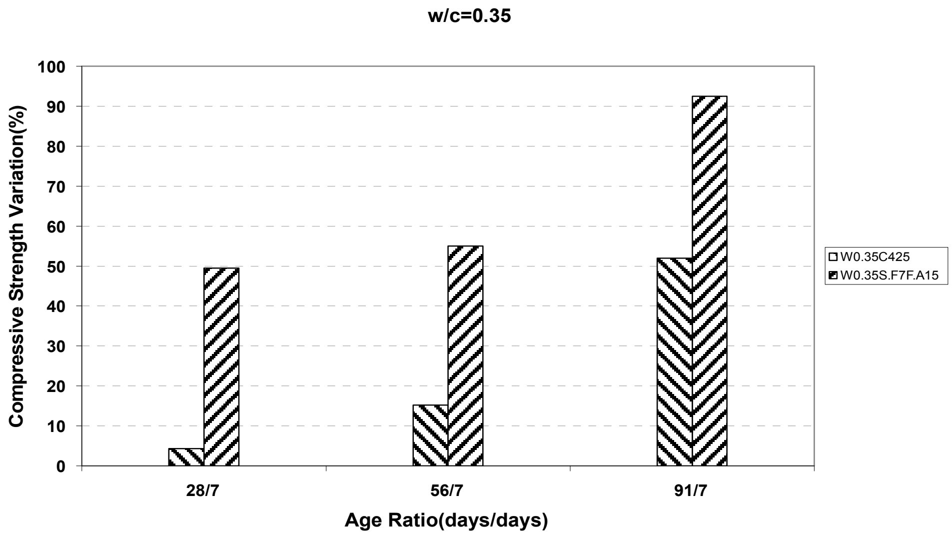

Figure 5. Variation of compressive strength ratios (w/c:0.35)

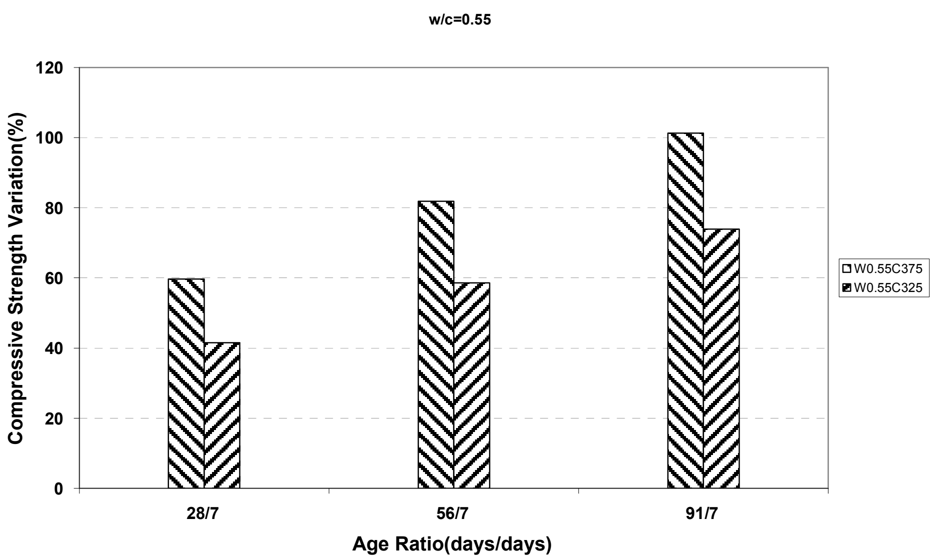

Figure 6. Variation of compressive strength ratios (w/c:0.55)

Setting Times Determination. The setting times of the concrete mixtures containing different pozzolan materials were determined accordance to ASTM C403 and the results are given in Table 3.

Table 3. Setting times of concrete mixtures

Mix code	Setting Time(hours)	
	Initial Setting	Final Setting
W0.55C375	7.5	10.42
W0.55C325	8.08	10.92
W0.45C375	6.83	9.67
W0.45S.F7	6.92	10.17
W0.45C425	6.25	9.17
W0.45F.A15	7.5	10.25
W0.45F.A25	7.67	10.75
W0.45S25	7.58	10.67
W0.45S35	8.08	11.33
W0.35C425	5.67	8.83
W0.35S.F7F.A15	6.92	10.08

The results generally declared that the pozzolans retarded the setting times of the mixtures. These results may be attributed to the combined effects of cement content and dosage of superplasticiser (SP). In the pozzolanic mixtures, which cement was replaced partially with pozzolan, the dosage of superplasticiser increased. In other words, since the part of the cement was replaced by the pozzolans the admixtures efficiency in the mixtures increased (Ramachandran and Malhotra, 1995; Nonat and Mutin, 1992). The general effect of SP is to retard the setting times of concrete and the extent of retardation depends upon the type and dosage of superplasticiser, type of cement and cement compound, particularly C_3S and C_3A. The retardation of hydration is due to adsorption of super-plasticizer over the surface of cement particles. Therefore, for the concrete mixes containing pozzolan, due to the lower amount of cement and higher effective SP dosages, a greater retarding effect could be expected. On the other hand the water cement ratios acted as an effective parameter on setting times. Increasing of water-cement ratio led to increase of setting times; the minimum setting times is belonging to the 0.35 water cement ratio specimens. For comparison of the results, the relative initial and final setting times for different concrete mixes are depicted in Figure 7. As shown the setting times of the pozzolanic mixtures increased compared to the reference specimens; and increasing the water-cement ratio led to an acceleration of setting times. These results can be considered as a practical guidance for estimation of setting times of pozzolanic mixes. Subsequently, the relationships between compressive strength at early age and final setting time (except the mixture that contain fly ash and silica fume) are illustrated in Figure 8. As shown the higher the setting time led to the lower compressive strength.

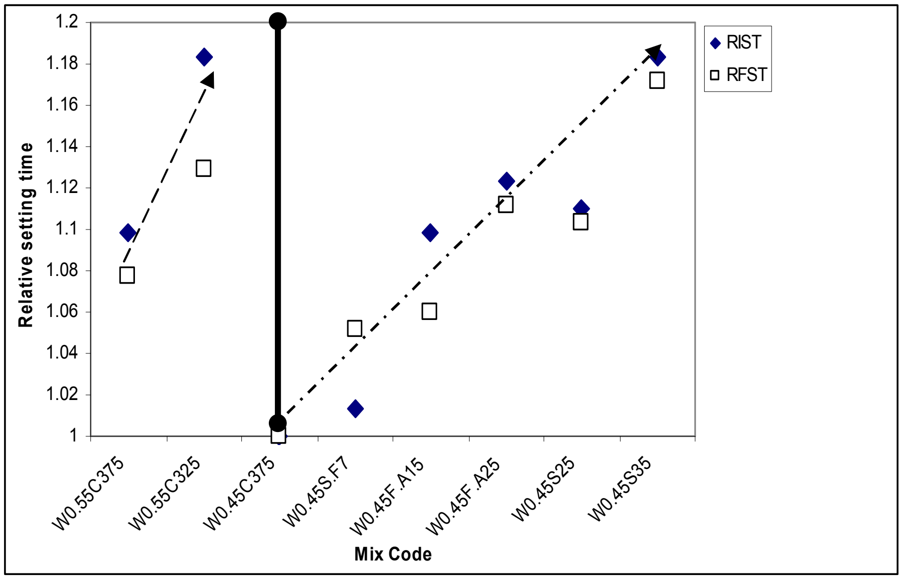

Figure 7. Effects of different pozzolan materials and cement content on the relative initial (RIST) and final setting times (RFST)

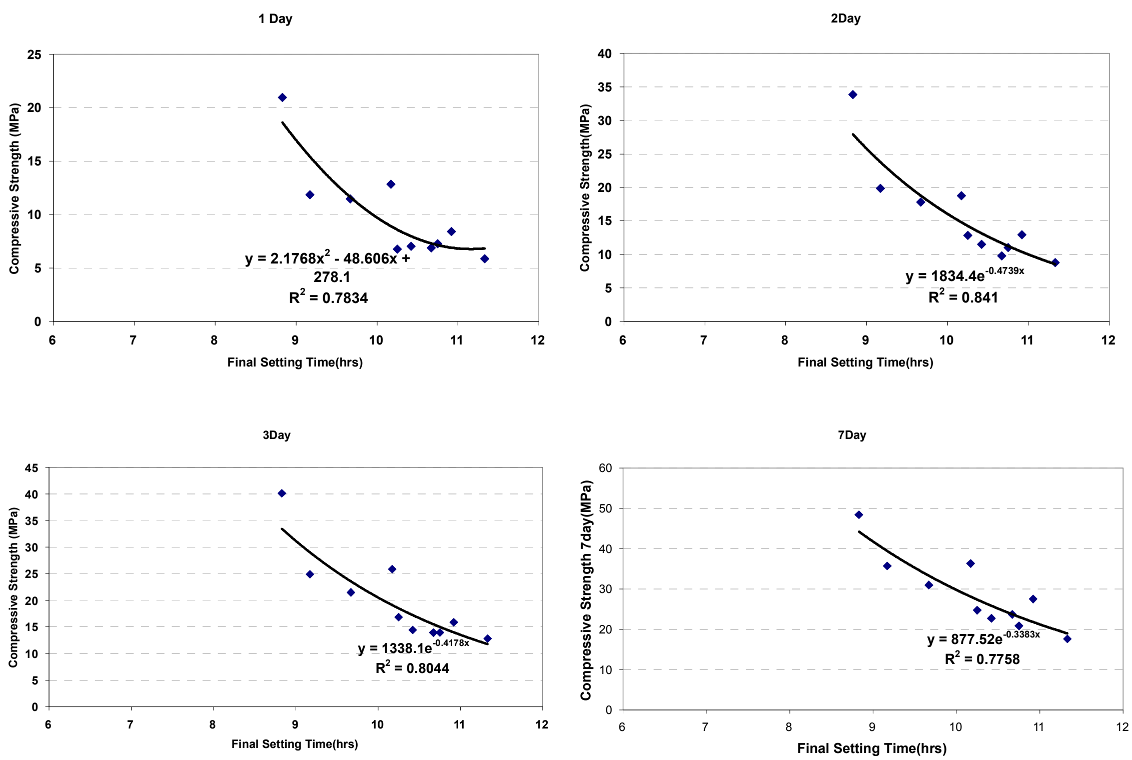

Figure 8. Compressive strength and final setting time relationships of the mixtures

The regression analysis was done and the following relationships were obtained between the final setting time and compressive strengths at the early ages.

$$f_{c1}= 2.1768t_f^2-48.606t_f+278.1 \quad (1)$$

$$f_{c2}= 1834.4e^{-0.4739x} \quad (2)$$

$$f_{c3}= 1338.1e^{-0.4178x} \quad (3)$$

$$f_{c7}= 877.52e^{-0.3383x} \quad (4)$$

Where,
t_f is final setting time (hr) and
fc_i represent the compressive strength at predetermined ages.

The results declared that a relative good agreement was attained between the early age strength and final setting time. As shown the 2, 3 and 7 days compressive strength can be expressed as exponential functions of final setting time (t_f). Whereas, a polynomial function was more precise for 1 day compressive strength estimation.

CONCLUSIOS

From the results presented in this paper, the following conclusions can be drawn:

1- Silica fume, fly ash and slag generally retarded the setting times of the concrete compared to the reference ones.
2- Retarding effect of pozolanic specimens may attributed to the low cement content and high efficiency of the super-plasticizer on the cement grains.
3- The maximum setting times was belonging to 35% slag specimens.
4- The lower the water cement ratio led to the decreasing of setting times.
5- The early age strength of the pozzolan specimens, except for silica fume samples, was lower than those for Portland cement samples.
6- Adding of fly ash enhanced the later age strength of the specimens more effective than Portland cement and slag.
7- Simultaneous utilization of fly ash and silica fume in the low water cement ratio mixes increased the later age compressive comparing to those for no pozzolan specimens.
8- A polynomial function of final setting time was found for expression of 1 day compressive strength; whereas exponential functions of final setting time were more precise for expression of the compressive strength at ages of 2, 3 ad 7 days.

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